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RESEARCH ARTICLE

IMPROVEMENT SOIL BIOLOGY CHARACTERISTICS OF PADDY FIELD BY SYSTEM OF RICE INTENSIFICATION

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ABSTRACT

The aim of the research was to test the System of Rice Intensification (SRI) method in improving the biological properties of paddy soil. The indicators of improvement were measured by the number of earthworm feces (cast), and the population of some microbial and nutrient content in the cast. The experiments were performed by comparing the three methods, namely: (1) SRI, (2) semi-conventional, and (3) conventional, using Randomized Completely Block Design. Each treatment was repeated nine times. The experiments were performed in the paddy fields belonging to farmers in Sukoharjo, Central Java. The result showed that the SRI (application of 1 tons ha^{-1} of vermicompost + 50% of inorganic fertilizer dosage) tends to increase the number of earthworms cast. It is an indicator of earthworm activity in soil. Earthworms cast contains more phosphate solubilizing bacteria (12.98 x 10^{10}cfu) and N content (1.23%) compared to its surrounding soil. There is a close functional relation between earthworms cast with total tiller number. SRI method is better than the other two methods to improve the biological characteristics of paddy soil that has the potential to maintain the sustainability of soil productivity.

Keywords: earthworms cast, SRI, paddy, soil microorganism, conventional sytem

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INTRODUCTION

Sustainability of soil function is very important for supporting rice production system in Indonesia to ensure continuity of food availability to the peoples. The rice production system in Indonesia to be less and less sustainable although many years experience with rice intensification effort. Rice production technologies, especially using chemical inputs (conventional method) have been upsetting the ecological balance in irrigation rice systems. Soil productivity and rice production were seen to be stagnant, levelling off, and some places even declining (Gani et al. 2002).

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Several soil factors can affect the low production of rice in irrigated rice ecosystems, including low organic matter, soil fertility and water availability (Jackson et al. 2005; McLeod 2009). One indicator of paddy field fertility degradation is its organic matter content less than 2% (Syamsiyah et al. 2007). Ideally, soil organic matter content to maintain soil fertility is around 5% (Brady, 1990). A key factor in maintaining the sustainability of soil productivity is to take care of soil organic matter (McLeod 2009). Organic C content in many irrigated paddy soil, especially in Java, has been decreasing (Las et al. 2006). Tangketasik et al. (2012) said that most levels of soil organic material in irrigated paddy soil in Bali, ranging from low to moderate. It is important to find strategy improve and maintenance soil fertility.

Sustainable soil fertility has a strong correlation with the consortium of soil biota. As a resource biota, soil biota consortium acts indirectly to soil productivity, such as a decomposer, N-fixer, P-solubilizing, and biological control of destructive biota (Swift and Anderson 1993). Sustainable land management should be directed to protect and increase role of resource biota, and minimize destructive biota (Susilo et al. 1999). Some factors can affect population and activities of soil biota, i.e: continuity of food availability, food preferences, microclimate, soil type, interaction with another soil biota, and surface cover by vegetation. Soil organic matter is the main energy source for most of the soil biota (Paul and Clark, 1982).

System of Rice Intensification (SRI) is one of environment friendly systems for paddy (Anugrah et al., 2008). The implementation of SRI is based on 6 important components: (1) young seedling transplantation between 8-15 days, with horizontal root and 1-2 cm in depth, (2) one seedling per hole, (3) row spacing 25 cm x 25 cm or wider, (4) irrigation is intermittent, (5) 2-4 times revocation weeds before primordial, (6) applying organic matter (compost) as much as possible before plating (Syam, 2006). Higher level of production could be achieved by SRI method (Gani 2002). Result of two years respective experiments using SRI technology in Indonesia showed production increase around 5.3% to 51.4% (Gani et al., 2004).

Rice cultivation using SRI potentially more increase soil organic matter and soil biota than conventional systems that use inorganic fertilizers only. Some farmers also combine conventional systems by adding organic fertilizers such as manure. Such cultivation practices in this paper called semi-conventional system.

Vermicompost is a good quality organic fertilizer. Vermicompost is the decomposition product of organic solid waste by earthworms gut and egested as casts (Janagan et al. 2003). Vermicompost contains plant growth hormones, high levels of microbial populations and soil enzymes, and tend to hold more nutrients over longer periods without adverse impacts on the environment (Ndegwa & Thompson 2001). Vermicompost can be used as a bioinoculant to reclaim acid soils, higher calcium contents of vermicompost can neutralize soil acidity and the suppression of labile aluminum (Mitchell & Alter 1993), good source of nutrients for plants, and improve the soil physical properties (Ferreras et al. 2006). Vermicompost could also affect plant growth indirectly through effects on soil microflora and microfauna (Brown & Doube, 2004; Kaushik & Garg 2004). Vermicompost has been reported significantly suppressed the arthropod pest populations, significantly decreased pest damage, make the plants less attractive to the pests, but they also had considerable effects on pest reproduction over time (Arancon et al. 2007).

Increasing soil biota and their services to soil ecosystem can indirectly measurement by the number of earthworm cast, some microbial diversity, and their nutrient characteristics compared to the surrounding soil. High cast production on surface soil indicates the high earthworms population and activity. This paper aims to convey information of SRI effects using vermicompost on improvement of earthworms' cast and their soil biology characteristics compared to conventional systems and semi-conventional using cow manure as usually used by farmer.

MATERIAL AND METHODS

The experiment was conducted at farmer's paddy field in Sukoharjo, Central Java, with geographics position on 110° 51' 04" – 110° 53' 20" E and 7° 34' 02" – 7° 35' 15' S. Laboratory analysis was conducted in Agriculture Department of Sebelas Maret University, Surakarta. Materials used in this experiments were IR-64 paddy variety, vermicompost, cow dunk, urea, and phonska.

The experimental design using Randomize Completely Block Design (RCBD) with a single factor (paddy cultivation management), comprise 3 levels (SRI, conventional, semi-conventional). Each treatment was repeated 9 times. The details of paddy cultivation management treatments showed in Table 1.

The observed variables include quality of vermicompost, cow dung, and soil properties (pH H_2O, organic matter content, water content, total N, P, K, P and K availability, C/N ratio, and CEC); earthworms feces or cast (dry weight per ha, organic matter content, total bacteria, total fungi, and population of phosphate solubilizing bacteria) compared to surrounding soil.

Cast measurement

The cast is earthworm feces that looked like a pile of agregate grains and commonly found in surface soil. The cast is an indicator of earthworm activities and is a stable macroaggregate that rich of nutrients (Lee, 1985; Lavelle and Spain, 2001).

Cast production was measured based on earthworms' feces found in nine wood frames of 25x25 cm^2, laid randomly on each treatment. Determination of cast dry weight was done by taking cast sub-sample found in each frame. The cast dry weight per frame is used to calculate cast dry weight per ha. Another sub-sample of the cast was used to determine their chemical and biologi characteristics.

Tabel 1. Comparison of SRI, conventional and semi-convensional management treatments

Management	SRI	Conventional	Semi-conventional
Plowing	2 (two) times	2 (two) times	2 (two) times
Water management	Intermittent	Flooded	Flooded
Seedlings	12 days	21 days	21 days
Row spacing	25 cm x 25 cm	20 cm x 20 cm	20 cm x 20 cm
Seed number per hole	One	2 to 5	2 to 5
Organic fertilizer	1 ton/ha vemicompost	without organic fertilizer	5 ton/ha of cow dung
Inorganic fertilizer dosage	50% dosage*	100% dosage *	100% dosage *
Organic fertilizing schedule	1 week before planting	-	1 week before planting
Inorganic fertilizing schedule	3 times (0.3 part spread at 7 DAP#; 0.4 part at 21 DAP; and 0.3 part at 30 DAP)	3 times (0.3 part spread at 7 DAP#; 0.4 part at 21 DAP; and 0.3 part at 30 DAP)	3 times (0.3 part spread at 7 DAP#; 0.4 part at 21 DAP; and 0.3 part at 30 DAP)
Harvesting	When rice grain have been hard and leaf color has been yellow	When rice grain have been hard and leaf color has been yellow	When rice grain have been hard and leaf color has been yellow

Remarks : *SRI = system of rice intensification; *100% dosage of inorganic fertilizer was 300 kg ha^{-1} urea and 400 kg ha^{-1} Phonska; #DAP = day after planting*

Statistical Analysis

All datas interprated using analysis package software, Minitab version 16.

RESULT AND DISCUSSION

Paddy soil characteristics

Paddy soil used for this study had low level fertility as indicated by the availability of N (0.06%), P (11.2 ppm), and K (0.14 me%) were very low to low categories, and also low of organic matter content (2.2%) and CEC (14.4 me%) (Table 2).

Reduction of soil organic C can be related to an imbalance between the amount of organic matter inputs compared to a number of organic C outflows. Conserve an adequate organic C stock in agricultural soils is primary importance for improving nutrient supply, soil structure, sustaining microbial activities, and maintaining suppressiveness against soil-borne pathogens (Scotti et al. 2015). Applying organic and inorganic fertilizer are very important to increase soil organic matter content and available soil nutrients. Cow dung is common organic fertilizer used by a farmer as fertilizer supplement in semi-conventional paddy management. Vermicompost is another type of organic fertilizer, which is of high quality and has a greater potential to improve nutrient availability and soil health.

Table 2. Paddy field characteristics before treatment

No.	Variables	Unit	Value	Categories
1	pH H_2O	-	6.10	Moderate*
2	Total N	%	0.06	Very low*
3	Total K	me%	6.75	Very low*
4	Total P	ppm	28.18	Moderate*
5	Available P	ppm	11.32	Low*
6	Available K	me%	0.14	Low*
7	Soil organic matter	%	2.20	low*
8	CEC	me%	14.40	Low*

Remarks : *Categorised by PPT (2005),
**Categorised by Puslitbangtanak (2004)

Table 3. Cow dung compost and vermicompost quality

Variable	Unit	Cow dung compost	Vermi-compost
pH_2O		6.96	7.89
Organic matter	%	81.88	86.42
Water content	%	20.87	65.93
Total N	%	1.33	1.82
Total P (P_2O_5)	%	0.16	1.30
Total K (K_20)	%	0.60	1.13
C/N ratio		35.61	29.20

Vermicompost and cow dung compost quality

In this research, SRI management using vermicompost as organic fertilizer, while semi-conventional management using cow dung compost. Vermicompost has higher quality than of cow dung compost (Table 3). Both of them use the same material, however, earthworms as the main actors at the vermicomposting process (Chaoui 2003; Carver and Cristie, 2008), whereas an actor in the cow dung composting are microbes. Earthworms actively as a biological simulator, produce enzymes of protease, lipase, amylase, cellulase and chitinase. They can convert biochemical rapidly to cellulolytic matters and proteinaceous from some organic waste (Sinha et al., 2002). Vermicompost can be used as a source of rich nutrients on crop land to improve soil structure, waterholding capacity, and enhances soil microbial activity (Kumar et al. 2009).

Cast production as an indicator of earthworm services

The cast is earthworm feces that looked like a pile of aggregate grains and commonly found in surface soil. The cast is an indicator of earthworm activities and is a stable soil macroaggregate that rich of nutrients (Lee, 1985; Lavelle and Spain, 2001).

The result of this research showed that treatment of 1 ton/ha vermicompost on paddy cultivation based on SRI showed the

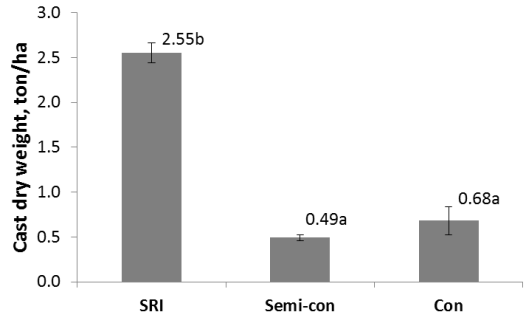

Figure 1. Cast production in paddy cultivation based on SRI, semi-conventional (semi-con) and conventional (Con) methods

highest cast production (2.56 ton/ha). It was highly significantly different ($p<0.01$) compared to the application of 5-ton cow dung compost or without organic manure on conventional paddy cultivation (± 0.59 ton/ha) (Figure 1).

Vermicompost is a mixture of earthworms feces and some decomposition level of organic waste used as the main material in vermicomposting. Cocoon (earthworms' egg) commonly found in vermicompost and will hatch on moist condition (Palungkun, 1999). Vermicompost application into soil potentially increases earthworms population. Earthworms population and their activities indirectly can measure the amount of cast production (Lee, 1985). The high number of earthworms cast implying a high population of earthworms . Paddy cultivation based on SRI with limited water will create a microaerobic condition. That condition is more suitable for earthworms growth and activities rather than on flooded soil such as conventional and semi-conventional system.

Based on correlation test, cast dry weight has a positive correlation to the number of tiller per hole ($r=0.89^*$), and N content in plant tissue ($r = 0.75^*$). N content in plant tissue has positive correlation significantly to N in the cast ($r = 0.77^*$). N content in cast is 1.23% (Table 4). The cast is earthworms feces that rich with N content (Carver and Cristie 2008). Vermicompost rich of plant nutrients including N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B. Uptake of which has a positive effect on plant nutrition, photosynthesis, the chlorophyll content of the leaves and improves the nutrient content of the different plant components (Theunissen 2010).

Soil microbiota population in cast vs surrounding soil

The soil is a habitat of a variety of soil biota, that has an important role in soil biological processes to support sustainable soil productivity (Izac, 2005). There was significantly different ($p<0.05$) between phosphate solubilizing bacteria, total bacteria, and total fungi in the cast and its surrounding soil (Table 4). Earthworms cast contains a high number of P-solubilizing bacteria, bacteria, and fungi population relatively to surrounding soil.

Application of 1 ton/ha vermicompost in SRI increasing P-solubilizing bacteria (PSB) both in the cast as well as the surrounding soil (Table 4). Earthworms interact with some microbiota in their gut (Lavelle and Spain, 2001), so that it is possible PSB excreted together with earthworms feces. PSB has an important role solubilize the unavailable P form so that become available P to plant (Paul and Clark, 1982).

Application of organic manure on a paddy field, using SRI as well as semi-conventional system, resulted in higher number of total soil bacteria population rather than the application of inorganic fertilizer only in a conventional system (Table 4). Vermicompost and cow dung as C and energy sources of most of the soil biota, so application both of them will be maintenance soil biota population.

Table 4. Soil microbiota population and nutrient content in cast vs. surrounding soil

		PSB, cfu	Bacteria, cfu	Fungi, cfu	pH	OM, %	N tot,%	P_2O_5, %
SRI	Cast	12.98 x 10^{10}b	22.18 x 10^{10}a	5.63 x 10^{2}b	6.72b	3.20a	1.23b	0.12a
Semi-con		85.00 x 10^{9}b	82.00 x 10^{10}ab	90.00 x 10^{2}b	6.60b	5.50b	1.06b	0.49b
Con		12.98 x 10^{10}b	93.75 x 10^{9}a	65.00 x 10^{2}b	6.28a	4.14ab	0.65ab	0.42b
SRI	Surrounding Soil	24.19 x 10^{10}b	24.48 x 10^{11}b	90.00 x 10^{2}b	6.21a	3.73ab	0.40a	0.17a
Semi-con		5.10 x 10^{9}a	32.27 x 10^{11}b	10.00 x 10^{2}a	6.10a	3.44a	0.45a	0.30ab
Con		10.83 x10^{9}a	21.30 x 10^{10}a	25.00 x10^{2}ab	6.11a	2.75a	1.26b	0.09a

Remarks : SRI = system of rice intensification; Semi-con = semi conventional; Con = conventional; PSB = phosphate solubilizing bacteria, cfu = colony forming unit; OM = organic matter. The number in the same column was followed by same letter are not significant different

Soil bacteria consortium has variety of role to support sustainable soil function, such as nitrification, ammonification, symbiotic and non symbiotic N fixer (Paul and Clark, 1982; Schulte and Kelling, 2006; Simanungkalit et al., 2006). Soil fungi has an important role in soil biological processes, such as a decomposer of organic matter, nutrient cycle, etc. Soil fungi also have a role in soil aggregation, because their mycelium bind soil particles and create stable soil aggregate (Gilling and Holmes, 2004).

Earthworms cast also contains a high number of organic matter and soil nutients, especially Nitrogen (Table 4). Earthworms cast typically have high N contents which suggests that they would be good sources of plant N (Chaoui et al. 2003). The availability of N is important to support plant vegetative growth such as for tiller formation. Application of vermicompost and cow dung have an important role in increasing soil organic matter in a paddy field.

Soil biota services to plant growth

Soil biota acts as natural actors of several of soil biological processes, that has important role to support growth and plant production directly or indirectly (Jackson et al., 2005). Application of vermicompost and cow dung manure using SRI or semi-conventional system in paddy cultivation significantly increase total tiller number per hole ($p<0.05$). Paddy cultivation using SRI showed highest total tiller number per hole (± 49 tillers per hole) while conventional system showed ± 34 tillers number per hole.

SRI uses only one seedling per hole while conventional system uses more than one seedling per hole. Seedling age used in SRI (12 days) is younger than seedling age used in conventional system (14 days) (Table 1). The condition created by SRI is more suitable for the seed to grow freely, resulting more tiller number than a conventional system.

Application of vermicompost and cow dunk on paddy cultivation using SRI or semi-conventional system shows the increasing population and activities of soil biota (Tabel 4). This experiment result showed an important role of soil biota services to vegetative growth of the plant. The total tiller number per hole has positive correlation to soil bacteria (r = 0.63*), soil fungi population (r = 0.71*), cast dry weight (r = 0.89*), N content in cast (r = 0.77*), and pH H_2O in cast (r = 0.65*).

Based on stepwise regression analysis, showed that total tiller number per hole has functional relation ($p < 0.01$) to cast dry weight, N content in cast, and total soil bacteria population, based on the equation 1.

*Total tiller number = 1.52 + 4.99 cast dry weight + 6.71 N in cast + 2.06 soil bacteria population ($R^2_{adj.}$= 0.97**) ..... (equation 1)*

Application of organic matter increases earthworms cast production in a paddy field. The cast of earthworms has rich amount of soil microbiota, organic matter, and nutrients (Table 4). The enrichment of cast by organic manure apllication in a paddy field, affect the population of soil biota and the amount of nutrient available to plant become abundance. It has very important role in supporting the sustainable of paddy field productivity and paddy growth and reproduction.

SRI is a paddy cultivation system using intermittent water management while a conventional system using flood water management continuously (Syam, 2006). That condition can affect growth and activities of soil biota. Intermittent water management creates aerobic environment condition in a paddy field so that organic matter decomposition and mineralization run smoothly. Continuously flood condition creates anaerobic or facultative aerobic environment condition so it will retard any soil biological activities (Paul and Clark, 1982). Paddy cultivation based on SRI more empower of soil biota services in paddy field and its also efficient in water and seed using (Mutakin, 2009).

CONCLUSIONS

1. SRI using 1 ton/ha vermicompost is more improvement of soil biota services in paddy field rather than semi-conventional and conventional system, which were indicated by the highest cast production (2.55 ton/ha). There is a close functional relation between earthworms cast with total tiller number.
2. Earthworms cast contain more phosphate solubilizing bacteria population and total Nitrogen than its surrounding soil.
3. Application of vermicompost and cow dunk in paddy cultivation based on SRI and semi-conventional system produced more population of soil microbiota and organic matter, rather than without application of organic manure.

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